AFAMRL-TR-83-080

INVESTIGATION OF THE EFFECTS OF Gy AND Gz ON AFTI/F-16 CONTROL INPUTS, RESTRAINTS, AND TRACKING PERFORMANCE

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AFAMRL-TR-83-080

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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

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20. ABSTRACT (cont)

This sensitivity study showed about a 150 percent improvement to active tracking performance and approximately a 400 percent improvement in performance on passive tracking tasks when the shoulder restraint pads were used. Marked performance degradation without shoulder restraints was seen beginning at approximately ±1.5 Gy. Results obtained during sustained +Gy and -Gy were equivocal, but showed the same general trend. This investigation also revealed the possibility of potentially hazardous inadvertant and inappropriate control cross coupling resulting from the acceleration environment. Throttle pitch pointing, rudder, and roll imputs were the most notable. Useful information was also developed concerning pilot fatigue from multiple, sequential exposures to Gy; and further insight was obtained into difficulties with maintenance of viewing position with respect to the head-up display.

SUMMARY

A group of AFTI/F-16 Project Test Pilots was subjected to sustained and oscillating lateral accelerations ranging from 1 Gy to 2 Gy in 0.25 Gy increments while performing complex tracking tasks. The acceleration environment was produced by the Air Force Aerospace Medical Research Laboratory's human centrifuge, the Dynamic Environment Simulator. During exposures, the pilots were restrained with either a conventional lap belt and shoulder harness system, or with that system augmented by shoulder restraint pads similar to those being considered for incorporation in the AFTI/F-16.

This sensitivity study showed about a 150 percent improvement to active tracking performance and approximately a 400 percent improvement in performance on passive tracking tasks when the shoulder restraint pads were used. Marked performance degradation without shoulder restraints was seen beginning at approximately ±1.5 Gy. Results obtained during sustained +Gy and -Gy were equivocal, but showed the same general trend.

This investigation also revealed the possibility of potentially hazardous inadvertant and inappropriate control cross coupling resulting from the acceleration environment. Throttle pitch pointing, rudder, and roll inputs were the most notable. Useful information was also developed concerning pilot fatigue from multiple, sequential exposures to Gy; and further insight was obtained into difficulties with maintenance of viewing position with respect to the head-up display.

A1

PREFACE

The research documented in this report was conducted as a part of a continuing program conducted jointly by the Acceleration Effects Branch of the Biodynamics and Bioengineering Division of the Air Force Aerospace Medical Research Laboratory, and the AFTI/F-16 Advanced Development Project Office of the Air Force Wright Aeronautical Laboratory.

Previous reports in this series have dealt with the evaluation of new restraint concepts proposed for use in the ±2 Gy dynamic acceleration environment of the AFTI/F-16, and with the viability of rudder tracking as a control implementation for the use of the direct side force capabilities of this six degree of freedom (6DOF) aircraft. The previous work and the work reported here were conducted by the joint team, using the unique capabilities of the AFAMRL human centrifuge, the Dynamic Environment Simulator.

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Section 1
INTRODUCTION

The research objectives of this effort were as follows:

1. To quantify the threshold of tracking degradation, if any, imposed by levels of Gy ranging in 0.25 Gy increments, from ±1 Gy up to and including ±2 Gy, the maximum level in the AFTI/F-16 design.

2. To determine the presence and extent of any inadvertant cross coupling of control inputs into the AFTI/F-16 production throttle pitch pointing controller axis. This question to be investigated under the influence of both Gy and Gz on the left hand and forearm.

3. To determine the presence and extent of any inadvertant cross coupling inputs into the pitch and roll axes of the sidestick controller under the influence of Gy stress on the pilot.

4. To acquire data on a baseline level of tracking performance using a side stick controller functionally equivalent to an F-16 stick. A production stick was not available and a Measurement Systems, Inc., unit was used. This data will be used for comparison to an as yet undefined tilted (canted inboard) controller.

5. To further investigate the usability of the HUD when the subjects were using only an emulation of the aircraft canopy rail/bulkhead for lateral support with a normal harness array.

6. To quantify pilot neck muscle and back fatigue as a function of Gy level and duration.

Section 2
METHODS

Owing to the complexity of this experiment, the details of the task and system dynamics, and of the experimental design have been included in Appendix A and Appendix B in order to fully document these details of the experimentation. In what follows, only the general structure of the experiment is described and readers are referred to the appendices for complete details.

SENSITIVITY STUDY

With reference to Appendix B, it will be understood that the design of this experiment was completely randomized in order to wash out fatigue effects as much as possible, and to investigate thoroughly the performance degradation effects of increasing levels of lateral acceleration. In this study, only the IIA, IIB, and IC performance tasks were used because of the time and personnel constraints involved with using project test pilots as subjects. The order of presentation of the randomized lateral acceleration pulses and task characteristics were as follows:

Without Shoulder Restraints

1. Static baseline tracking of the performance task for training purposes.

2. Baseline tracking, same performance task, centrifuge arm in motion, subject exposed to +1.5 Gz.

3. Tracking under lateral acceleration; a series of five acceleration peaks of 30 seconds duration, maximum acceleration randomized over the peaks between 1 and 2 Gy in 0.25 Gy increments, 30 seconds of rest at baseline Gz between peaks. All lateral accelerations positive in sense (+Gy).

4. Five minute rest period at baseline Gz.

5. Repetition of 3 above, followed by baseline and static tracking epochs. All lateral accelerations positive in sense (+Gy).

6. Rest period ad lib at baseline Gz.

7. Repetition of 1 through 5 above, same performace task, all accelerations negative in sense (-Gy).

8. Rest period.

9. Static tracking of performance task for training purposes.

10. Baseline tracking.

11. Tracking under closed loop conditions (subject commanding acceleration), lateral acceleration peaks dynamically varying from 1 to 2 ±Gy, order randomized as above, duration, and rest periods as above.

12. Five minute rest period at baseline Gz.

13. Repetition of 11 above, followed by baseline and static tracking epochs.

14. Miscellaneous exposures at up to +6 Gz, closed loop to investigate throttle pitch pointing errors at high +Gz.

15. Rest period of not less than 1 hour.

With Shoulder Restraints

Exposures as in 1 through 15 above were duplicated, the only difference being the addition of the shoulder pad restraints designed to limit torso motion in ±Gy acceleration conditions.

PERFORMANCE TASKS

Two different tasks were used. In the open loop exposures, in which the subject had no control of the magnitude of acceleration and in which the acceleration was sustained in either the positive or negative directions, the task consisted solely of tracking the roll axis motion of the target display. In Appendix B, this is referred to as the IIA and IIB active tracking task.

While performing the active tracking task, the subjects were required to maintain airspeed at 500 knots and altitude at 10,000 feet. No disturbing inputs were provided to airspeed, altitude, yaw, and pitch under these conditions. In Appendix B, these tasks are referred to as passive tasks.

The second task was used only in the closed loop exposures. In these, the rudder inputs provided by the subject controlled the gimballing of the centrifuge cab to produce dynamic conditions of positive or negative Gy in response to the lateral excursions of the target display. Under these conditions, disturbing functions (described in Appendix A) were present in the target pitch and yaw axes; and the subject was required to actively track the motions of the target. In the IC exposures (Appendix B), these were the active tracking tasks. As in the open loop sustained exposures, the subjects were required to maintain airspeed at the nominal 500 knots, the altitude at the nominal 10,000 feet, and (in these cases) the roll angle at zero. In the IC exposures, these are the passive tracking tasks.

TASK DYNAMICS

Considerable effort was expended prior to this experiment to make the task dynamics match the characteristics of the basic F-16. This was done by repeated iterations and trials by project pilots and engineers until general agreement was reached that the match between centrifuge, displays, and tasks was as good as possible. The final simulation dynamics are documented at length in Appendix A and will not be discussed here.

TASK DISPLAYS

The display seen by the subjects consisted of a head-up display (HUD) sized to be equivalent to the HUD display in the aircraft. Vertical airspeed and altitude scales were provided as well as the standard pitch ladder, aiming circle, and roll tab displays. Initial plans called for the use of a view limiting device which would simulate the field of view of the wide angle HUD which is planned for the AFTI/F-16. This aspect of the experiment proved impractical to implement but previous reports in this series have documented the likelihood of difficulty in using the HUD at ±2 Gy.

SCORING

Immediately following each trial under each condition of experimentation, performance feedback was given to the subjects in the form of digital readouts presented on the display video monitor. Two scoring items were used; one for the average RMS error of the active tracking task, and the other a weighted average of all the passive tracking tasks.

DATA ACQUISITION

All data from these experiments were recorded digitally for subsequent analysis. On-line stripchart recordings were made of the electrocardiogram, throttle advance/retard, throttle pitch pointing, pitch, yaw, roll, Gz, and Gy acceleration channels for quick look analysis of the data.

ELECTROMYOGRAPHY

As an adjunct to the evaluation of subjective fatigue on the part of the subjects, measurement of electromyography (muscle biopotentials) was carried out by Wing Commander, David Reader, and his support team from the USAF School of Aerospace Medicine. The results of this effort will be reported separately.

COCKPIT FURNISHMENTS

As indicated in Appendix B, a production AFTI/F-16 throttle incorporating the pitch pointing feature was provided and installed in accordance with cockpit layout drawings. No production sidestick controller was available, and this control function was implemented with a Measurement Systems, Inc., force stick of nearly identical characteristics. Exact replicas of the cockpit bulkhead and a portion of the canopy profile were made and installed. These structures were positioned on the right and left hand sides of the seat in the proper relationship and extended from roughly the plane of the seat back, forward approximately 2 feet so as to provide a realistic throttle installation and to evaluate whatever use they might have as a support for the hands and forearms.

Section 3
RESULTS

CLOSED LOOP WITH YAW AND PITCH TRACKING

This portion of the experiment represents the most demanding of the tasks and the most realistic, since the pilot subjects were in control of the dynamic acceleration environment.

Analysis of Variance: Yaw/Pitch Tracking

1. There is a significant difference between ±Gy levels (.0001).

2. There is a significant difference between restraints (pads superior) (.0001).

3. There is a significant interaction between the ±Gy level and the subjects (e.g., the subjects react differently to the stress) (.0001).

Based on the Duncan Multiple Range Procedure, the following statements can be made about the observed differences with 90 percent confidence:

1. The tracking performace at ±2 Gy is significantly different than under any other condition.

2. The tracking scores at 1.0, 1.5, and 1.75 (taken as a group) do not differ from each other, but do differ from the baseline scores.

3. The scores at 1.0, 1.25, and 1.5 ±Gy are not significantly different, but they differ from the baseline scores and from the scores in the set of 1.0, 1.5, and 1.75. This observation is taken to represent the uncertainty concerning the exact location of the knee of the ±Gy sensitivity curve.

Analysis of Variance: HUD Tracking

1. There is a significant difference in tracking performance between ±Gy levels (.0001).

2. There is a significant difference in HUD tracking performance between subjects (.0001).

3. There is a significant difference between restraints (pads superior) (.0007).

4. There is a significant interaction between subjects and restraints (.05).

5. There is a significant interaction between subjects and acceleration level (.0001).

Based upon the Duncan Multiple Range procedure, the following statements can be made about the observed differences in HUD tracking with 90 percent confidence:

1. Tracking at ±1.5 and ±1.75 is not significantly different but tracking at these levels differs from all other tracking.

2. Tracking at 1.0, 1.25, 1.5, and 2 ±Gy is significantly different (worse) than at baseline conditions.

3. Prerun and postrun baseline tracking scores differ; postrun inferior to prerun performance. May be attributable to motion artifacts of centrifugation and some disorientation.

OPEN LOOP ROLL TRACKING (+Gy)

Analysis of Variance Roll Tracking

1. There are significant differences between tracking scores at different Gy levels (.0061).

2. There is a significant difference between restraints; pads superior (.0001).

3. There are significant interactions between subjects and Gy levels, subjects and restraints, and subjects/Gy/restraints. These are not considered to have an important bearing on the questions being asked.

Of these differences, the Duncan procedure reveals ony that 1.75 Gy differs from all other conditions, a situation for which there is no ready explanation, and that none of the other Gy levels or baseline scores are significantly different from one another.

Analysis of Variance HUD Tracking

1. Gy levels are not significantly different with respect to HUD tracking (.09).

2. There is a significant differences between restraints, pads superior (.004).

3. There are the expected differences between subjects, and subject/restraint interactions.

OPEN LOOP ROLL TRACKING (-Gy)

Analysis of Variance Roll Tracking

1. Tracking at different levels of Gy was not significantly different between levels.

2. As in all other cases, the pads were significantly better in terms of tracking scores (.0056).

3. There are significant differences between subjects, and significant subject/restraint interactions were seen.

Analysis of Variance HUD Tracking

1. Tracking with pads was significantly better than without (.0001).

2. Tracking at various G levels did not differ level to level with any great significance. As in other cases, there were significant differences between subjects; and there were significant subject/restraint interactions.

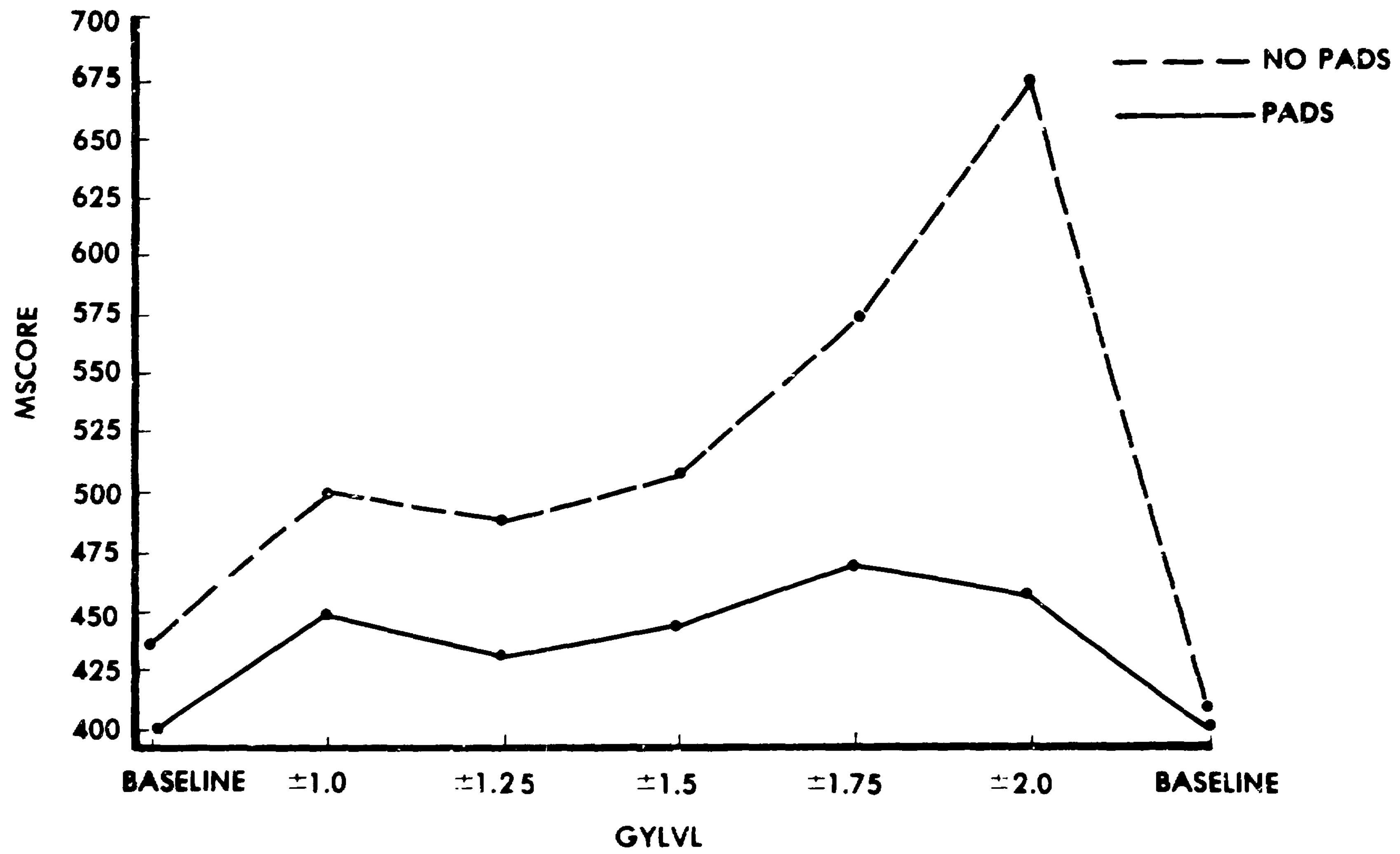

Figure 1. Closed Loop Tracking Error in Yaw and Pitch Under ±Gy (Oscillating)

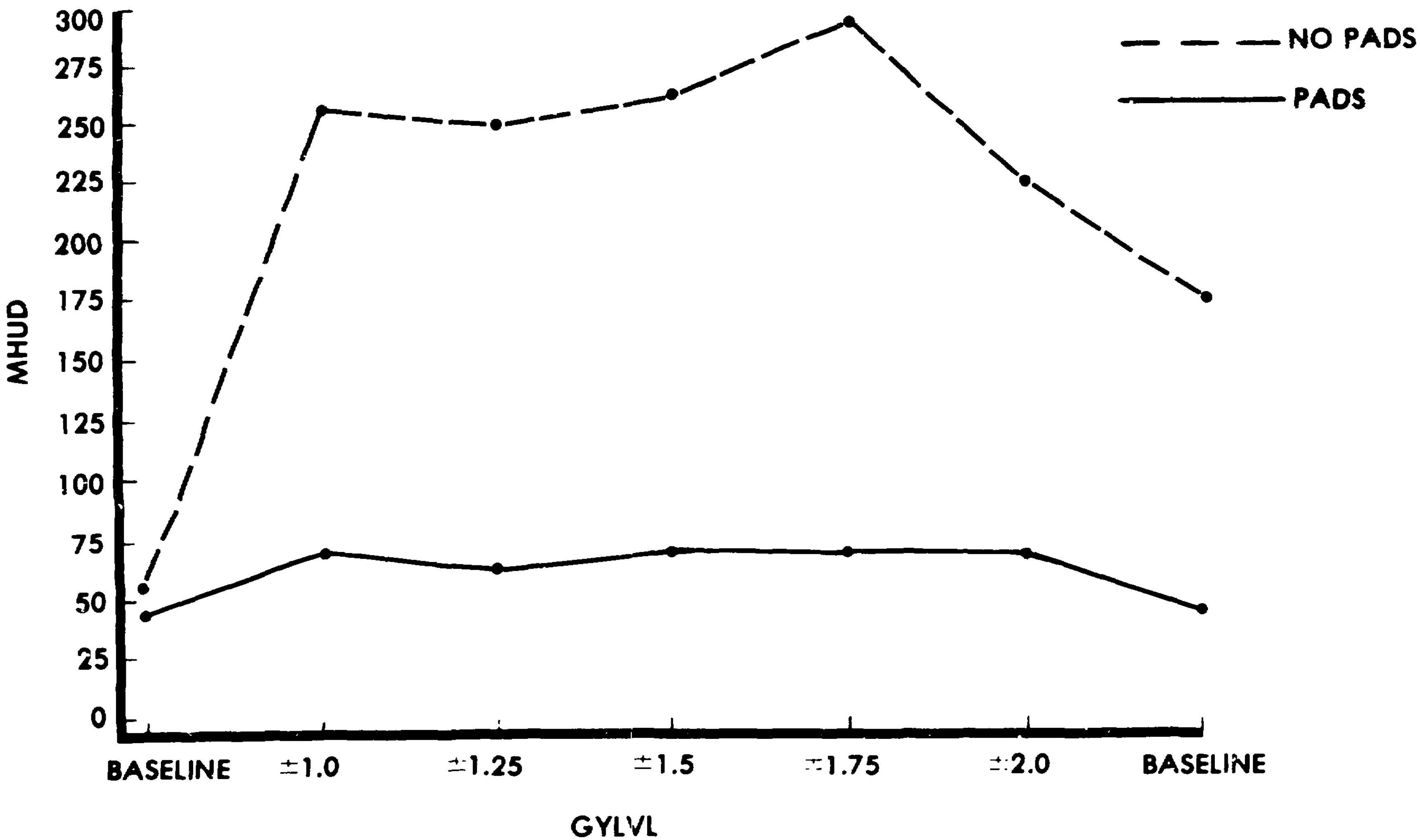

Figure 2. Closed Loop HUD Tracking Error (Passive Airspeed, Altitude, and Roll) Under ±Gy (Oscillating)

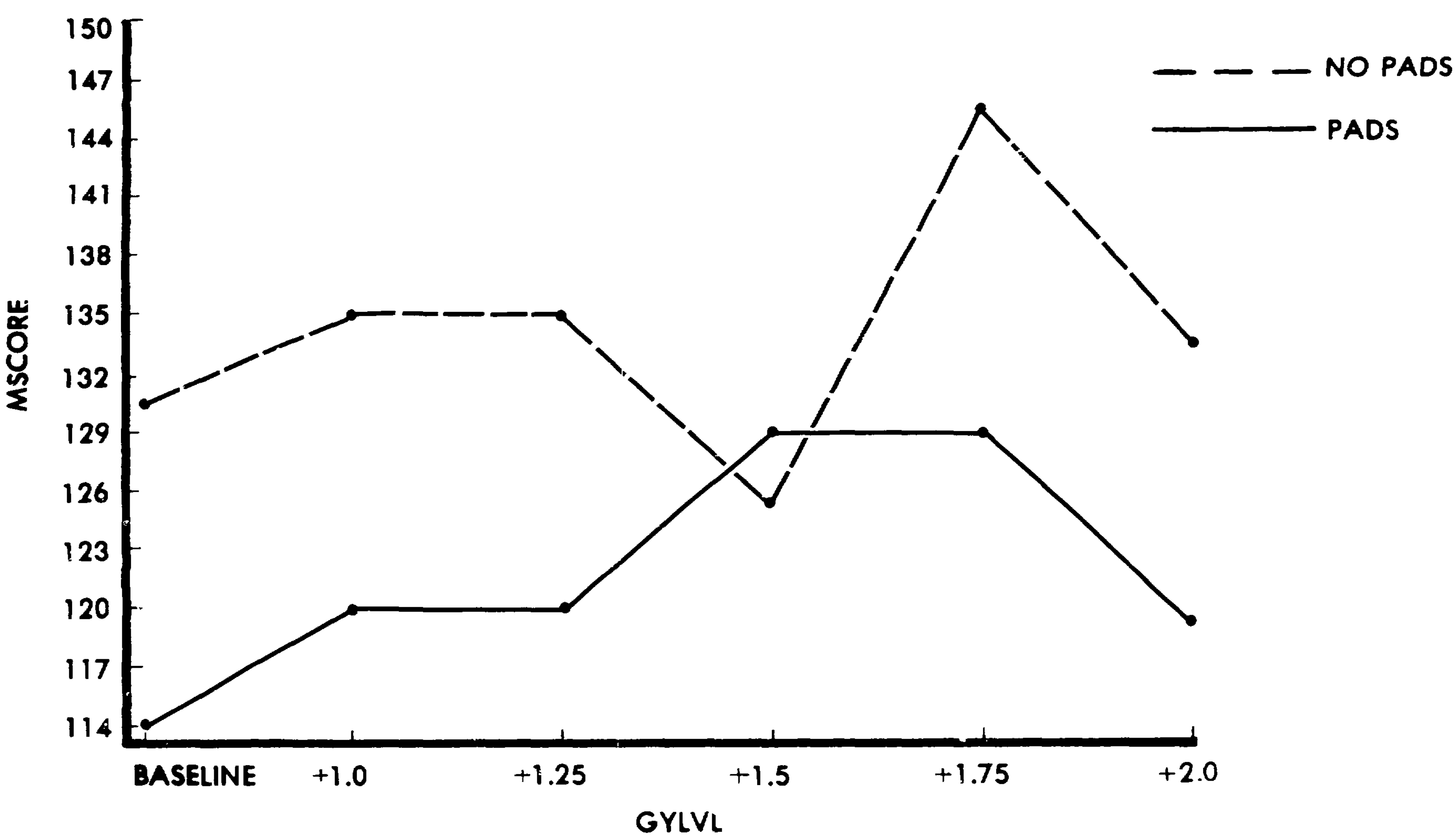

Figure 3. Open Loop Tracking Error in Roll Under Gy (Sustained)

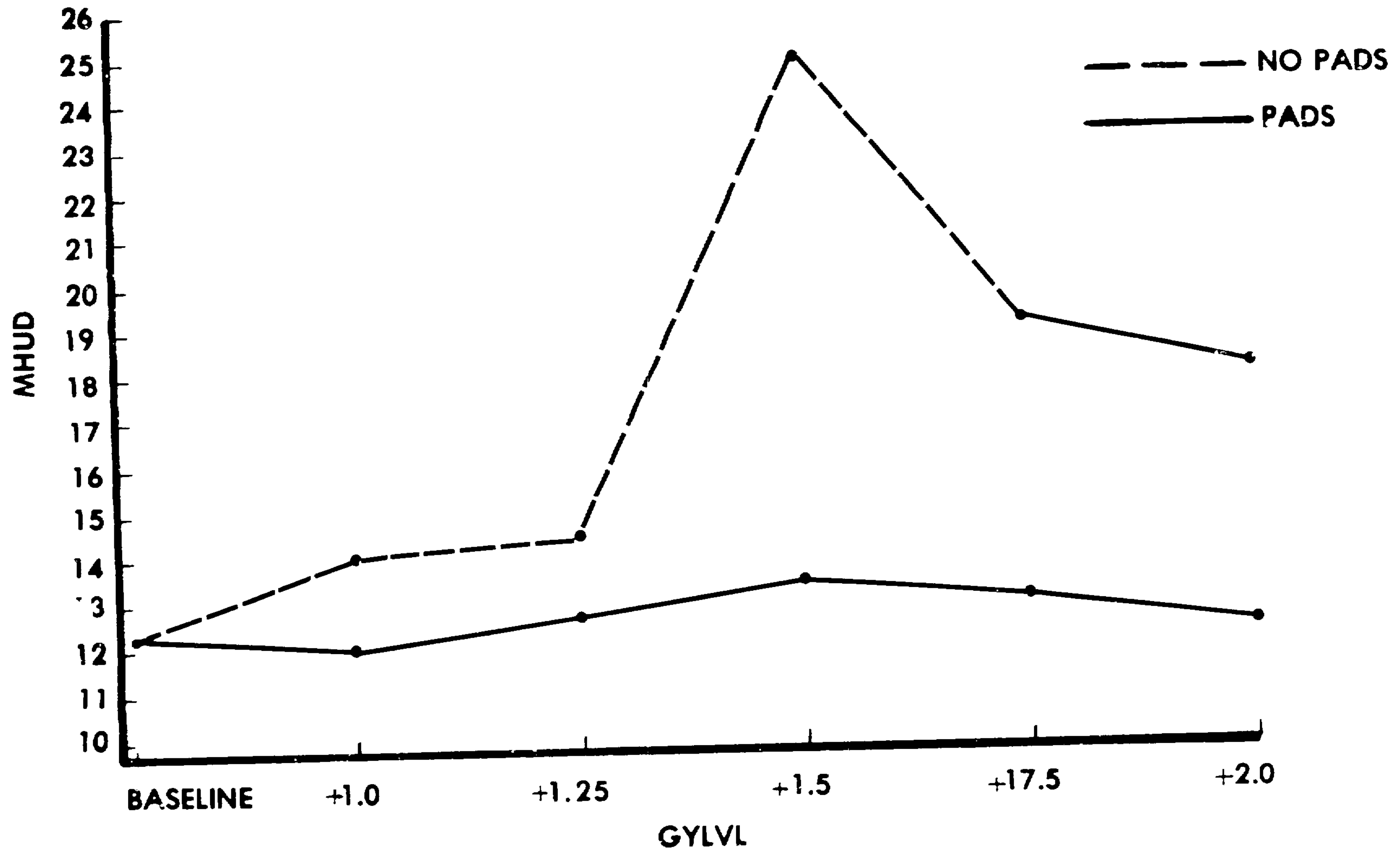

Figure 4. Open Loop HUD Tracking Error (Passive Airspeed, Altitude, and Roll) Under Gy (Sustained)

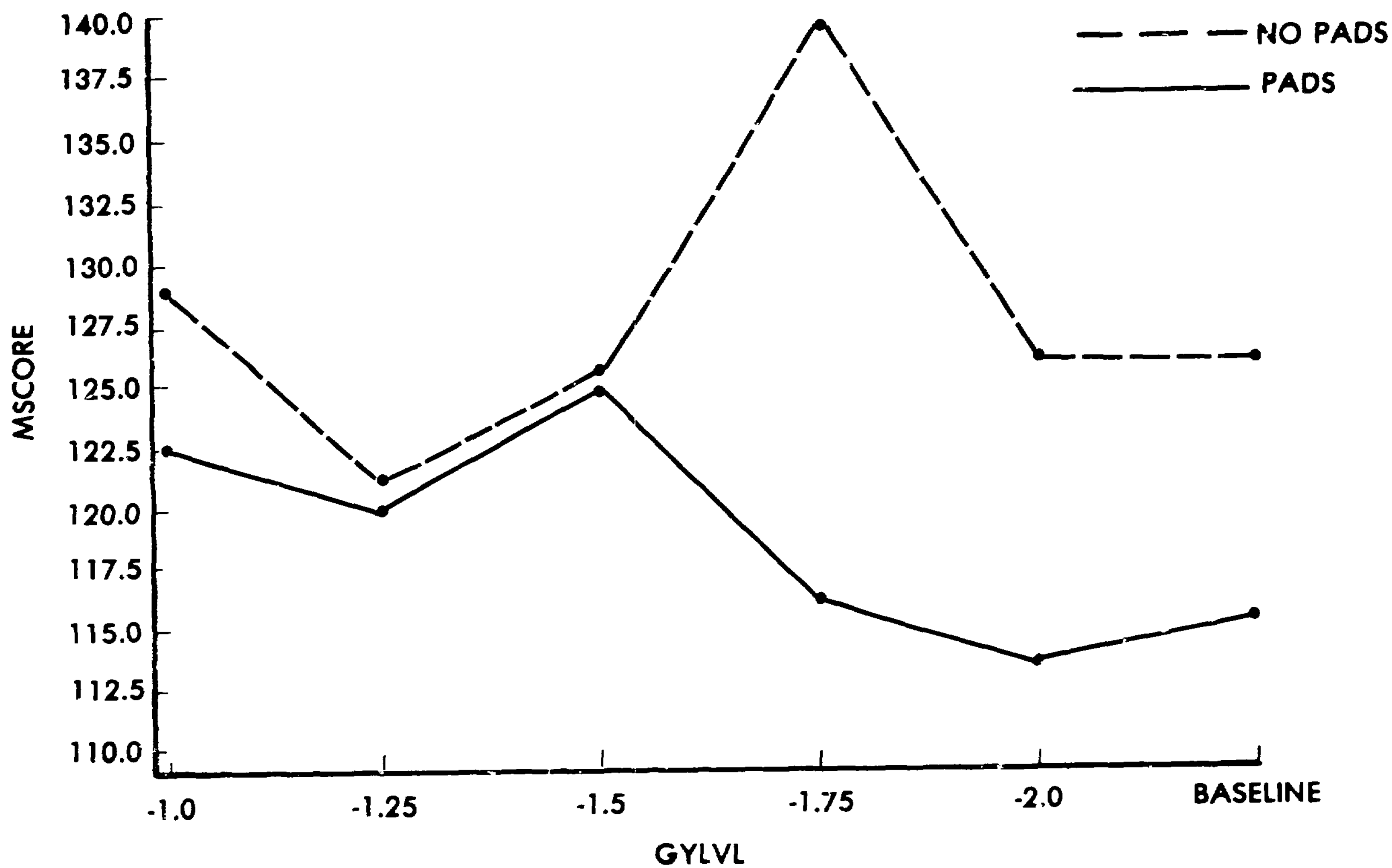

Figure 5. Open Loop Tracking Error in Roll Under -Gy (Sustained)

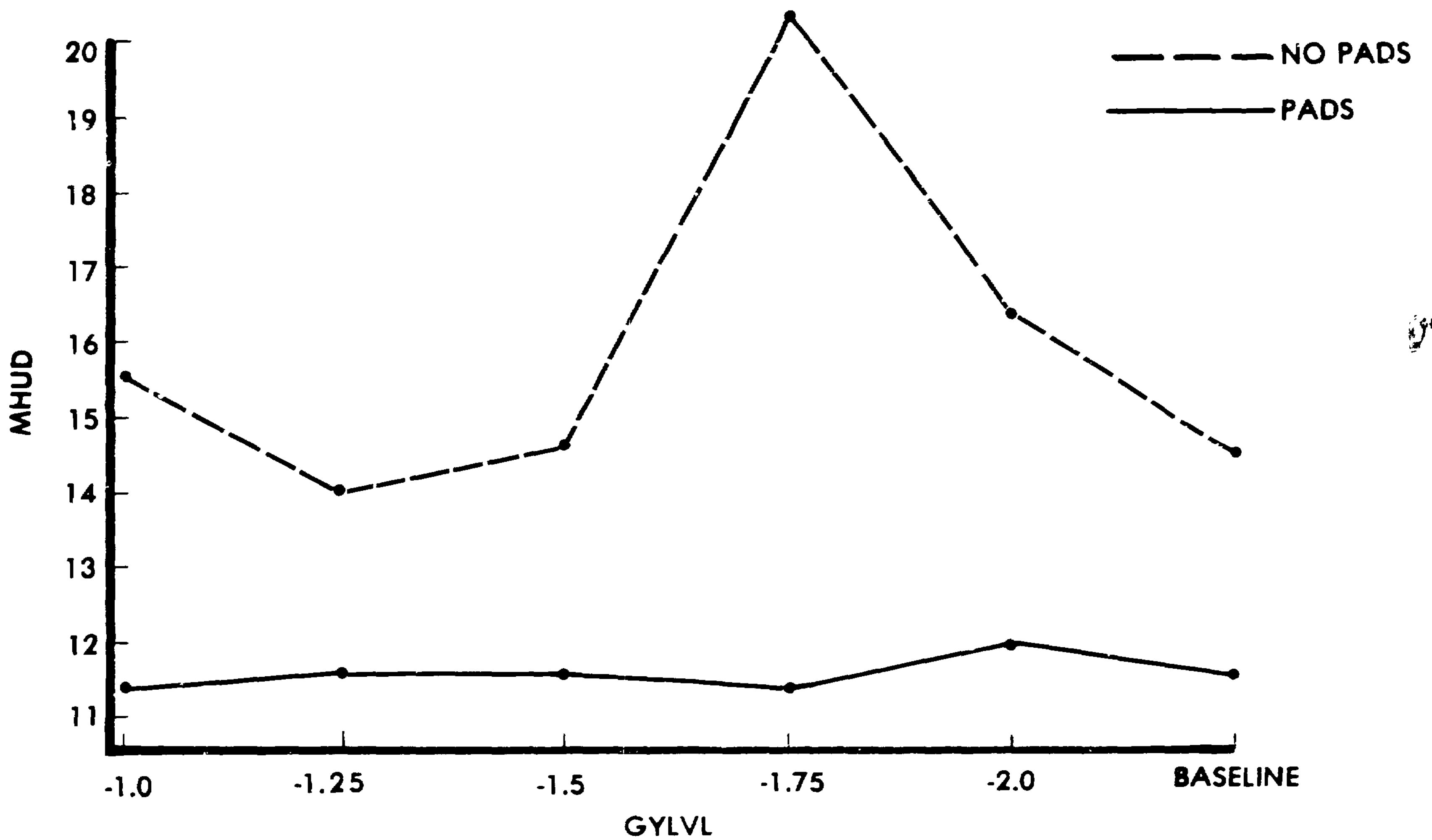

Figure 6. Open Loop HUD Tracking Error (Passive Airspeed, Altitude, and Roll) Under - Gy (Sustained)

CROSS COUPLING EFFECTS

Throttle Pitch Pointing Errors

Under the provisions of the Indoctrination Protocol, the subjects were permitted closed loop control of the centrifuge Z axis acceleration at levels up to +6 Gz in order to examine the occurrences of pitch pointing errors when moving the throttle from idle to afterburner. The essential results of this portion of the experiment are shown in Figure 7 and the accompanying table, showing a maximum pitch down input of 30 percent full scale in the afterburner position. Not shown is this table is one 50 percent pitch down error observed at the idle throttle position. No significant pitch pointing errors were observed under conditions other than sustained Gz, except for the closed loop yaw/pitch tracking epochs. Pitch pointing errors in the pitch up direction were seen as high as [illegible] percent, with pitch down errors reaching as high as 18 percent.

Stick Pitch Errors

Under the sustained acceleration conditions, during which the only active tracking task was the roll task, pitch errors of very large magnitudes were seen. At onset, pitch up errors of as high as 80 percent full scale were seen with reversals to 40 percent full scale down. At 1 Gy, the pitch errors dropped about 30 percent from the values seen at higher levels.

Rudder Errors

Rudder errors were most often seen during the onset of sustained accelerations and ranged from 10 percent to 50 percent of full scale. The direction of the errors indicate that the pilots were bracing themselves against the inertial forces. This was most pronounced in the runs without pads.

Roll Errors

These were seen at very high levels during the dynamic yaw/pitch tracking epochs. Above ±Gy, these were two to three times the level of the errors seen with the same task under baseline conditions. At baseline, the roll errors were approximately 15 percent full scale.

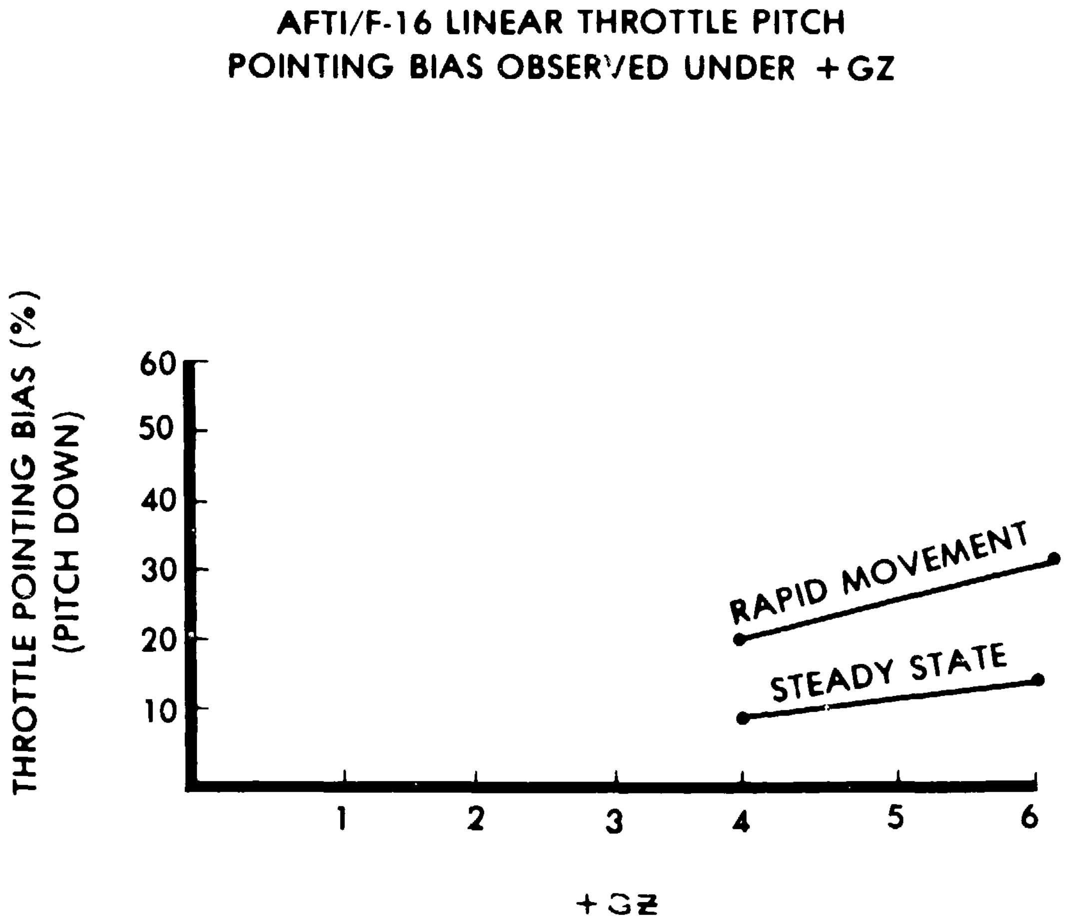

Figure 7. Throttle Pitch Pointing Errors Under Various Levels of +Gz Acceleration

TABULATED DATA

POINTING BIAS OBSERVED

	GZ CONDITIONS 2	4	6
SUBJECT 1			
STEADY STATE	NOT OBSERVED	5	NOT OBSERVED
RAPID MOVEMENT		15	
SUBJECT 2			
STEADY STATE	8	13	25
RAPID MOVEMENT	15	25	30
SUBJECT 3			
STEADY STATE	5	8	10
RAPID MOVEMENT	10	36	30
SUBJECT 4			
STEADY STATE	5	10	15
RAPID MOVEMENT	5	15	20
AVERAGE OF ALL SUBJECTS			
STEADY STATE	6	9	17
RAPID MOVEMENT	10	23	27

NOTE -Values indicate throttle pointing bias in percent of total pointing (Pitch-Down) authority available (See notes above).

Table 1. Table of Throttle Pitch Printing Errors Under Various Levels of +Gz Acceleration

Section 4
CONCLUSIONS AND RECOMMENDATIONS

SENSITIVITY OF TRACKING PERFORMANCE TO LATERAL ACCELERATION

The results of this research clearly show that without special restraints tracking performance is severely degraded above ±1.5 Gy. It is also clear that, on balance, tracking while using shoulder restraints is superior irrespective of whether the lateral acceleration is sustained or dynamic. All experimentation to date supports this conclusion.

While recognizing that the shoulder restraints being proposed for use in the AFTI/F-16 pose serious difficulties in terms of pilot mobility and access to side consoles, we nevertheless strongly recommend that the seat/restraint systems proposed for any six degree of freedom production aircraft be designed at the outset for pilot support in lateral acceleration. AFAMRL is prepared to consult on such future designs.

CONTROL CROSS COUPLING

Throttle Pitch Pointing

This research has shown that large throttle pitch pointing (TPP) errors occur under relatively high Gz acceleration loads. Clearly, the implementation of this control function could be improved to mitigate or eliminate this problem. The following actions are recommended:

1. Project test pilots must be warned of the likelihood of inadvertant pitch-down inputs under high accelerations in the Z axis. These are more common when the throttle is moved to the afterburner position, but also occur when the throttle is moved to the idle position.

2. Consider a redesign of the TPP mechanism. We recommend incorporation of a concept similar to the grip safety found on the standard issue Colt 45 ACP pistol. This concept would require that the pilot squeeze the body of the throttle handle in order to enable the pitch

pointing function. If this, or some other suitable mechanization, is not practical in the AFTI/F-16, recommend it be incorporated in any future production throttle designs. AFAMRL is prepared to consult on any such future designs.

Pitch and Roll Errors

This research has shown that high magnitude, inappropriate errors occur irrespective of the nature of the lateral acceleration. It is suggested, as in previous research on this issue, that it might be worthwhile to consider some control law scheme to reduce or eliminate these inadvertant inputs. If this is not practical in the AFTI/F-16, consideration to this issue is required in the design of any future six degree of freedom production aircraft.

Recommend that the project test pilots be warned of the presence of these cross coupled, inadvertant inputs.

Rudder Errors

Significant rudder errors have been clearly shown. These are most common during the onset of lateral acceleration and probably result from an instinctive reaction to brace on the rudder pedals, especially at levels above ±1 Gy. There are indications that these inputs are worse when the pilot does not have the shoulder pads to assist in restraint.

Recommend that project test pilots be warned of the likelihood of significant yaw errors during the onset of lateral acceleration.

FATIGUE

The electromyography measurements made during these experiments will be reported separately as noted in the body of this report. On a subjective basis, it is clear that at least one pilot complained of significant muscle soreness one day postrun. This subject had been exposed to the complete experimental series, both with and without shoulder pad restraints. At present, we are inclined to doubt that the closed loop dynamic runs make a large contribution to fatigue, since the muscle groups involved are not ordinarily subjected to sustained stress in either direction. The sustained acceleration runs assuredly do present the necessity for sustained muscular straining and are, therefore, the most likely to produce subsequent muscle soreness.

We recommend that in the development of tactics for the AFTI/F-16 aircraft lateral acceleration profiles flown in a single day not exceed the exposures to sustained acceleration pulses which were used in this experiment.

This research has reinforced the requirement for a lightweight helmet. Recommend its continued development and use in the AFTI/F-16.

HUD LINE OF SIGHT

As noted in the Section 2 of this report, it was not possible to implement the geometric surrogate of the HUD exit pupil because of space limitations within the gondola of the centrifuge. However, valid measurements of the head displacements of this group of test pilots were provided in the previous report in this series. Recommend the manufacturer be consulted and a simple experiment be conducted to determine if the HUD will be usable in the face of the measured head/eye displacements.

Appendix A

SUMMARY OF THE DYNAMICS OF THE EXPERIMENT WITH TASK DESCRIPTIONS

The actual, physical dynamics of the cab in the roll axis can be written:

$$\frac{\theta p(s)}{U(s)} = \frac{1.7}{S + 1.7} \tag{1}$$

where θp is the vehicle pointing angle, U is the stick command in volts, and S is the Laplace Transform Variable. The break frequency of 1.7 radians/second is the physical limit of the roll axis. To prevent visual motion mismatch, the dynamics of the yaw axis simulation on the analog computer are made identical to Equation (1). In this manner, as the cab rolls, the visual display moves accordingly:

Yaw Axis

$$\frac{\theta \text{ yaw } (s)}{U \text{ yaw command } (s)} = \frac{1.7}{s + 1.7} \tag{2}$$

where U command is the output of the rudders.

The dynamics of the HUD in the pitch and roll axis were generated on the analog computer. They were described by:

Pitch Axis

$$\frac{\theta \text{ pitch } (s)}{U \text{ pitch command } (s)} = \frac{10}{s + 10} \tag{3}$$

For the roll of the HUD display, these dynamics were driven by

$$\frac{\theta \text{ roll HUD display}}{U \text{ roll command}} = \frac{20}{s + 20} \tag{4}$$

TASK DESCRIPTIONS

In the yaw axis, the forcing functions were of the form:

Final Lateral Task (30 ˬeconds of Data)

Sine Wave Number	Harmonic Number	nwo	AMP	$1/2\ (AMP)^2$	$20/\log_{10}$ AMP DB
1	2	.41887902	1.12	.6275	.984
2	5	1.04719755	.4897	.1199	-6.201
3	11	2.30383461	.1588	.0126	-15.98
4	17	3.56047167	.07066	.00249	-23.02
5	23	4.81710873	.04449	.000989	-27.03
6	31	6.49262481	.02974	.000442	-30.53
7	41	8.58701991	.01775	.0001576	-35.02
8	47	9.84365697	.014109	.00009953	-37.01
9	67	14.03244717	.011202	.0000627	-39.01
10	73	15.28908423	.008899	.0000396	-41.01
11	83	17.38347933	.00794	.0000315	-42.00

The amplitudes in column 4 were scaled by a factor Ky.. To get Ky, we compute the power in the forcing function as follows:

$$y = \text{Total power} = \sum_{i=1}^{11} 1/2\ (AMP)^2 = .76431$$

Then each litude is multiplied by Ky where

$$Ky \quad \sqrt{Ty} = 5 \text{ degrees RMS} \qquad (5)$$

In this mann.., the yaw axis forcing function has 5 degrees rms value.

For the roll and the pitch axis, the following forcing function was used:

The Slow - Roll - Pitch Task

Sine Wave Number	Harmonic Number	nwo	AMP	1/2 (AMP)^2	20/log$_{10}$ AMP DB
1	3	.62831853	1.166	.67978	-3.[illegible]53
2	7	1.46607657	.377	.071077	-8.47
3	13	2.72271363	.1339	.00897	-17.46
4	19	3.97935069	.0754	.00284	-22.45
5	29	6.07374579	.03778	.0007138	-28.45
6	37	7.74926187	.02524	.0003186	-31.96
7	43	9.00589893	.01893	.0001792	-34.46
8	53	11.10029403	.013402	.0000898	-37.46
9	61	12.77581011	.011945	.0000713	-38.46
10	71	14.87020521	.009709	.00004713	-40.26
11	79	16.54572129	.009487	.00004500	-40.46

Note:

$$\sum_{i=1}^{11} 1/2\ (AMP)^2 = .76413$$

Each forcing function must be scaled. To determine the scale factors K_{roll} and K_{pitch} which multiply the amplitudes, they are calculated as follows:

$$\text{using } Ty = \sum_{i=1}^{11} 1/2\ (AMP)^2 = .76413$$

$$K_{roll} \times \sqrt{Ty} = 20 \text{ degrees RMS}$$

In this manner, the roll tracking task has 20 degrees rms levels of dispersion on the CRT.

For the pitch axis, the amplitudes are multiplied by:

$$K_{pitch} \times \sqrt{Ty} = 2 \text{ degrees RMS}$$

In this manner, the pitch tracking task has 2 degrees rms levels of dispersion on the CRT.

Appendix B
EXPERIMENTAL PROTOCOL

I. IDENTIFICATION

1. Title: Investigation of the Effects of Gy and Gz on AFTI/F-16 Control Inputs, Restraints, and Tracking Performance 81-21

2. Date: 1 June 1981

3. Project/Task/Work Unit; 72311711

4. Principal Investigator: R. E. Van Patten
   Co-Investigator: J. W. Frazier

5. Medical Investigator: Major Ralph Luciani

6. Medical Monitors: George Potor, Jr., M.D., Major Ralph Luciani, or any other AFAMRL Qualified Physicians

NOTE:

1. All experimental conditions specified in this protocol fall below the maxima permitted by the Generic Sustained Acceleration Protocol. (80-10)

2. The tracking tasks required in this protocol, except for the possible addition of pitch and roll axis display perturbations, are generally the same as those used in the protocols titled: The Effects of Combined +Gz and +Gy on Human Operator Performance (80-20) and addendum thereto (File R-80-003) and AFTI/F-16 Phase 2: Rudder Pedal Tracking at +2 Gy (80-32).

3. The cockpit furnishments for this protocol are generically the same as those used heretofore except that an actual production F-16 throttle will be used in some experiments as well as an actual F-16

side stick controller which may also be used. These items are both flightworthy hardware. In addition to the shoulder restraints previously used, this protocol will make use of cockpit canopy and bulkhead structures which represent as closely as possible the actual operational cockpit environment. These furnishments have not been provided before. They are included in this protocol at the request of the Project Test Pilot in an attempt to determine if these surfaces will serve for restraint in the Y axis. It should be clearly understood that these structures will make subject removal in the event of a medical emergency more difficult. In view of the modest acceleration levels involved and the lack of any previous history of medical emergencies under the conditions which will be used, these structures should not present any difficulty. Nevertheless, emergency egress procedures will be tested following setup under the supervision of the panel physician, who will advise AFAMRL/SE of findings.

II. RESEARCH BASIS

1. Objectives: The objectives of the experimentation to be conducted under this protocol are listed below in order of priority. The accomplishment of all objectives will depend upon availability of time and subjects.

    a. Measurement of inadvertant pitch pointing activity using the production AFTI/F-16 throttle. Gy sensitivity study.

    b. Measurement of inadvertant pitch and roll signals from the side stick controller. Gy sensitivity study.

    c. Acquire data on a baseline level of tracking performance using an F-16 side stick controller, the data to be used in comparison to an as yet to be defined tilted (canted inboard) side stick controller. If the F-16 stick cannot be used, an MSI force stick will be used.

d. Investigate/quantify HUD usability when subjects are using only the cockpit bulkhead/canopy structures for lateral support (with normal harness array).

e. Evaluation of fatigue.

2. Relevance: The work to be done under this protocol is an extension of previous experimentation conducted in behalf of and at the request of the AFTI/F-16 Advanced Development Project Office (AFWAL/FII).

3. Background: Previous experimentation in this series has examined the questions of new restraints for the lateral acceleration environment of six degree of freedom (6 DOF) aircraft, specifically the AFTI/F-16 as well as the questions relating to the viability of rudder tracking as a control implementation for direct side force tracking in the Gy environment. The experimentation described in this protocol is the next step in the quantification of human operator performance in this new environment.

4. Experimental Plan:

a. Gondola Furnishments:

1. Currently installed modified F-16 seat/restraints. Shoulder harness may be locked or unlocked.

2. Preproduction or production F-16 elbow and forearm supports.

3. Emulations of the F-16 bulkhead and canopy (to a height of approximately 6 inches above the canopy rail). Subject will not be enclosed by a canopy. Installations will be provided port and starboard.

4. Emulation of the F-16 center console previously used.

5. Preproduction F-16 rudder pedals, production throttle.

Aside from the usual flight clothing and equipment, the subjects may be provided with experimental oxygen masks or regulators and lightweight helmets. Subjects will breathe either ambient air or 100 percent oxygen depending upon experimental requirements per section II.D.1.c. of Protocol 80-10.

b. Performance Task: The performance task to be implemented for the objectives stated in II.1.a., b., and c. will consist of the following:

1. Rudder tracking of a laterally moving target driven by the previously used Ai*sin (it + i) function. for this experiment, the maximum bandwidth of the forcing function shall be no more than one half of the cab axis drive system.

2. Pitch and roll tracking tasks shall be implemented by driving the target display in the vertical and roll axes. The forcing function for these shall be of the same generic form as that for the lateral tracking task except that the highest frequency component shall be 0.5 Hz for both vertical and roll forcing functions. The pitch (vertical axis) excursions of the target shall be limited to ±0.5 inch. The roll axis displacements shall be limited to ±45 degrees, rate limited to 45 degrees/second.

In the achievement of objective II.1.d., no tracking task is contemplated unless so requested by the participating test pilots. In that case, the performance task will consist of all or part of the tasks described in 1 and 2 above.

c. Experimental Exposures: See following page for the profiles to be used in the Gy tracking sensitivity study.

Definitions. In examining the tables on the following page, the following definitions apply.

Open Loop: A run in which the subject's control manipulations do not affect the motion of the centrifuge.

Closed Loop: A run in which the subject's control manipulation do affect the mtoion of the centrifuge. In this protocol, closed loop runs will involve cab vectoring to provide an oscillating Gy field.

Passive Tracking Task: Tasks associated with displays which are not driven by an forcing function. At the beginning of each run, subjects will be required to initialize these; and thereafter (during the run), the only disturbances in these control functions will be those generated by the subjects. The purpose of the passive tasks is to provide information on how the active tasks and the acceleration environment affect the passive tasks.

Example: Consider condition Ic. During a run of this type, the subject will be asked initially to position his throttle so that the indicated airspeed is 500 knots and to assure that the throttle pitch pointing mode is in the neutral position. He will be asked to level the wings on the display and line up with the zero pitch angle line. These are all elements of the passive tracking tasks. As the centrifuge reaches the necessary main arm speed, the active tracking task will appear on the display. In Ic, the target will move back and forth laterally; and the subject will track the target with the rudder pedals. The target will also move vertically at the same time, and the subject will track the vertical movement using the pitch axis of the side stick controller. During the run, the subject or acceleration induced movements in the roll, pitch pointing, and throttle position passive tasks will be recorded as well as the active tracking task error signals.

Run: A run will consist of a set of acceleration peaks (five in all), each separated from its predecessor by 30s at baseline acceleration. The run will commence with a peak of ±Gy, followed by 1.25 Gy, followed by 1.5 Gy, followed by 1.75 Gy, and finishing with 2 Gy. Each run will be preceded by a baseline data run at baseline Gz, and baseline Gz data will be taken following the fifth peak of each run. Each run shall be separated from the next run by a rest period of 5m at static conditions.

Typical Scenario for Data Acquisition (One Day)

a. Initial Training: No more than 20 trials under static conditions for familiarization on the active and passive tasks to be used during the day.

b. Baseline Gz Data: Four replications of both the tasks at baseline Gz.

c. Gy Sensitivity: Four replications of Series I condition, without special restraints. Four replications of Series II condition, without special restraints.

d. Rest Period: Not less than 1 hour.

e. Gy Sensitivity: Four replications of Series I condition, with special restraints. Four replications of Series II condition, with special restraints.

Summary: A daily exposure will consist of a total of 16 runs, under two conditions of restraint, for a given set of Series I and Series II conditions, either +Gy or -Gy or ±Gy so that only one condition of acceleration is used on a given day.

d. Method of Simulating the Acceleration Environment: Accelerations will be generated by appropriate main arm angular velocities, accompanied by cab vectoring to produce the sustained or oscillating lateral accelerati s. Maximum lateral acceleration will be ±2 Gy, with small transient excursions of short duration around this value which are generated under dynamic overshoot conditions as have been described in previous protocols.

e. Subjects: Primary subjects are expected to be military and civilian test pilots assigned to the AFTI/F-16 project or to other projects. The participation of these aviators will be subject to the approval of the Commander, AFAMRL, and contingent upon the presentation of adequate medical records provided to the attending physician prior to participation. Additional subjects may be drawn from the Acceleration Hazardous Duty Panel. All other aspects of subject use shall be in accordance with the requirements of the Sustained Acceleration Generic Protocol (80-10).

f. Experimental Conditions: See II.4.c above.

g. Data Collection and Analysis

1. Typical data to be collected during these experiments shall consist of digital recordings of:

   a. Time history of acceleration
   b. Time history of all elements of the simulation

      1. RMS rudder error
      2. RMS pitch error (equivalent to altitude error)
      3. RMS roll error
      4. RMS airspeed error (equivalent to throttle error and a function of pitch)
      5. Throttle pitch pointing variation
      6. Impedance electrocardiogram
      7. Electromyogram
      8. Pneumotachometer

2. Stripchart recordings may be provided for:

a. Electrocardiogram
b. G suit pressure
c. Gz
d. Gy
e. Impedance electrocardiogram
f. Electromyogram
g. Pneumotachometer

3. Analog tape recordings of subject voice.

4. Color or black and white, sound video recordings of the subjects during exposure.

5. Analysis of data obtained will consist of statistical measures appropriate to the type and amount of information obtained.

6. Reporting of the data shall be in accordance with the Sustained Acceleration Generic Protocol (80-10).

III. MEDICAL RISK AND SAFETY

All portions of this section of this protocol are in accordance with Sections III.A and B, IV, and V of the Sustained Acceleration Generic Protocol (80-10) except as noted in Section I, Note 4 above. No additional risks are anticipated.

The number of repetitions of the Gy exposures alone is above that experienced previously. The levels, however, are low with a maximum of 2 Gy. The objective limitations will, therefore, be those stated in the experimental plan but subjectively will be altered by the subject's fatigue and subsequent desire to terminate the experiment or by the medical monitor's judgment of the subject's fatigue. The rest periods, however, are adequate for evaluating fatigue before proceeding to subsequent sets of exposures. It is believed that the only potential problem will be fatigue which will be a result of coordinating muscular inputs and task objectives. Neck discomfort is anticipated and strain is possible but no serious misadventures are expected.